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ISTEF Active Imaging Program

by

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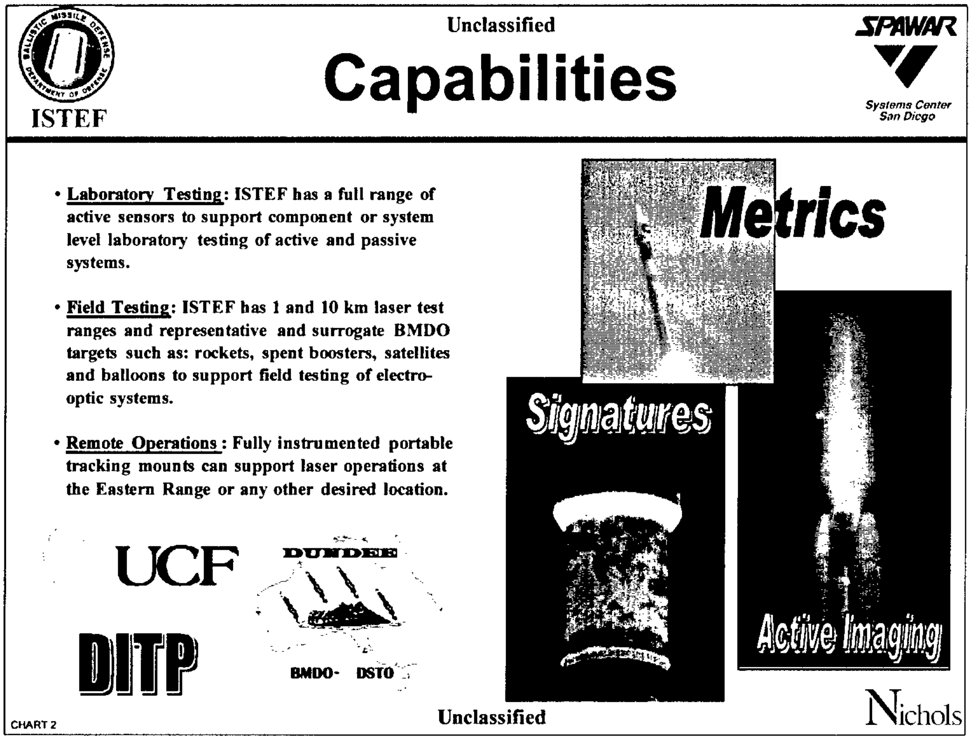
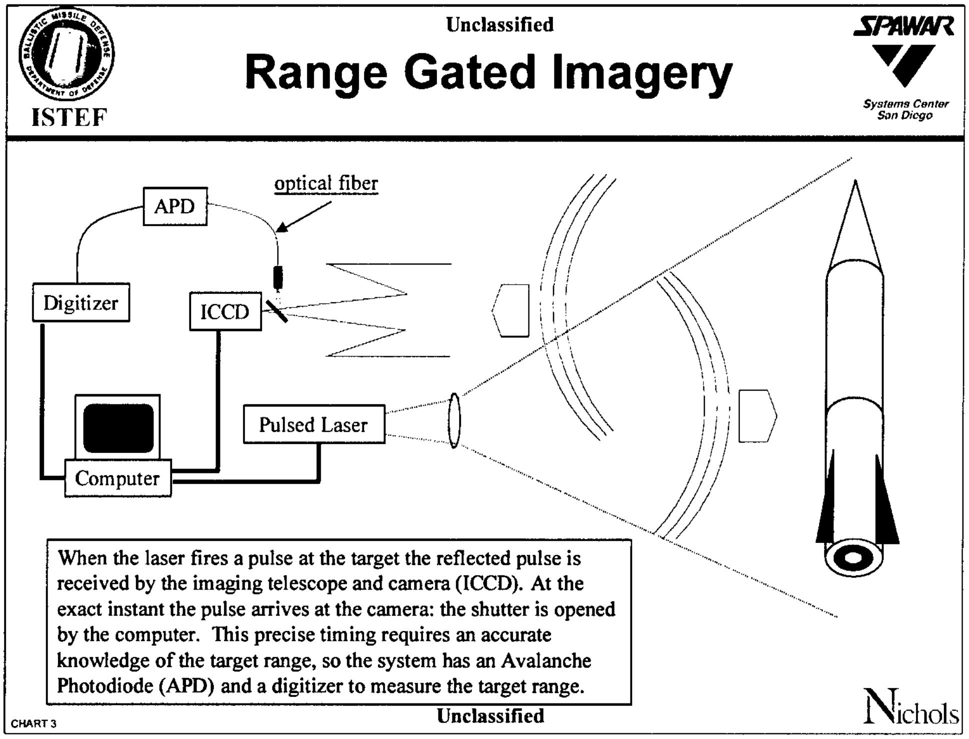
ABSTRACT

The BMDO Innovative Science and Technology Experimentation Facility (BMDO/ISTEF) active imaging program is engaged in an ongoing program to develop and demonstrate advanced laser imaging concepts for Ballistic Missile Defense (BMD). As an example, we present results from our support of the Eastern Range (ER) launch of the Titan B33 (Cassini). This support was a result of ER Range Safety's concerns over their inability to precisely monitor the status of the launch vehicle in the earliest stages of flight. Existing passive CCD video cameras are blinded by the bright solid rocket plume during the first few seconds of launch and, in the case of Cassini, this was a critical portion of flight. Several factors of this launch posed unique safety concerns. First, this space probe had a significant amount of Plutonium Oxide on board as a heat source for its Radioisotope Thermoelectric Generators (RTGs). Second, the Titan IVB launch vehicle had the new Solid Rocket Motor Upgrade (SMRU) with gimbaled nozzles and this was only its second flight. Third, the launch occurred at night, which compounded the effect of the bright plume on conventional CCD cameras.

We will also present our plans to upgrade our laser imaging system to include a polarization sensing capability. This upgrade is a joint venture with the University of Central Florida (UCF).



The Laser Active Imaging Program comprises one half of the laser research that is ongoing at ISTEF. The other half is the Laser Radar Program. Together these to areas of research make a unified approach to studying discrimination, sensing and phenomenology issues of interest to BMDO and DOD. ISTEF's unique position as a center of excellence in active sensing allows us to pursue ideas and concepts that more specialized sensor programs such as AST and SLBD can not. Having a broad charter allows us to work with other BMDO and DOD groups such as the AMSC and the USAF to solve current sensing problems while at the same time advancing concepts which are of direct applicability to advanced BMD concepts. For example, by supporting the active sensing needs of the Eastern Range during the TITAN/Cassini launch we gained valuable expertise *and equipment* that has greatly enhanced our ability to support the BMDO DITP program. The real-life knowledge we gain by supporting BMDO and DOD programs enhances our research efforts. In turn, this research enhances our ability to help other programs meet their data collection needs. It is this synergy between application and research that is the strength of the ISTEF laser program.



ISTEF uses a type of active imaging known as "Range Gated Imagery." This type of imagery uses a pulsed laser to illuminate the target and a high speed camera to capture the image. When the laser fires a pulse at the target the reflected pulse is received by the imaging telescope and camera (ICCD). At the exact instant the pulse arrives at the camera, the camera shutter is opened by the computer. This precise timing requires an accurate knowledge of the target range, therefore the system has an Avalanche Photodiode (APD) and a digitizer to measure the target range. Background light is rejected by using a very short shutter speed (as small as 100ns) and narrow band-pass filters (typically 3nm FWHM).

The short exposure means that the only targets within a narrow range "gate" or window are imaged. If the target is too close, the reflected pulse arrives before the camera shutter opens and if the target is too far away, the reflected pulse arrives after the shutter closes. This feature, of only imaging targets within a narrow range gate, means that targets such as low flying cruise missiles may easily be separated from ground clutter.

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The illumination Problem

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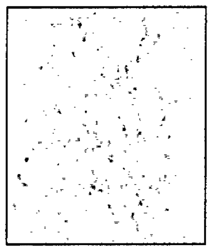
Speckle versus Beam Breakup

Speckle is the uneven illumination at a detector due to the surface roughness of the target

Beam Breakup is the uneven illumination of a target or detector due to atmospheric density fluctuation

Laser illumination
of a Delta rocket
(range = 4 km)



Illumination function
from image at left with
rocket body removed

- For most endo-atmospheric applications, beam breakup is usually a much bigger problem than speckle.
- Both problems may be mitigated by averaging multiple images.

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One of the major obstacles to obtaining high-resolution active images is uneven target illumination. For endo-atmospheric applications, uneven target illumination arises because of two contributing effects: one due to the target and one due to the atmosphere. The target produces an ***apparent*** uneven illumination of the detector when the highly coherent laser light interferes (destructively and constructively) with itself after reflecting from a rough target. The atmospheric effect arises because the air is not uniform in density. Density variation can arise from convection, wind, or thermal variations. Since the speed of light in air is density dependent, these small density variations will steer the beam like a lens or prism. If the size scale of these variations is much smaller than the beam (as in the images above) , then individual parts of the beam will be steered in different directions. The resulting illumination function is striated and uneven, similar in many ways to the illumination pattern seen on the bottom of a swimming pool when the sun interacts with waves on the water's surface.

Both types of aberrations, speckle and beam breakup, may be mitigated to some extent by averaging multiple image frames. This is especially effective when the laser beam is tracking a moving target.

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ISTEF Active Imaging

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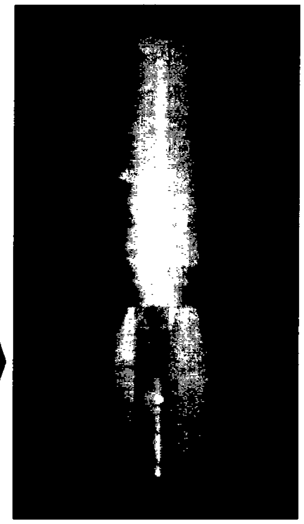
- **Advantages Over Passive Imaging**
  - No ambient light required
  - High contrast even in hazy conditions
  - Even image contrast (no blooming)
  - No motion blur
  - Complements passive data (emissivity)
  - Provides target range and Doppler
- **BMDO Applications**
  - Target ID
  - Kill assessment
  - Aim point selection
  - CSO discrimination
  - Cruise Missile Detection
- **ISTEF Innovations**
  - Fiber coupled detectors
  - Dual mode LADAR/Imaging
  - Calibrated LRCS
  - Transportable system

Active Image:
Titan B-33 Launch

Image of this surrogate BMD target is from the ISTEF transportable laser imager. The launch was at night (no ambient light). Notice the lack of a plume flair and the presence of a glint.



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Because active imaging uses laser light instead of ambient light to illuminated the target, it has several advantages over conventional passive imaging. These include: higher contrast under hazy conditions, less susceptibility to blooming, and the same image quality night or day. This last aspect of active imaging makes it ideal for automated target recognition and identification (ATR). Since active imaging uses reflected light of known intensity to image targets, the target reflectivity can be measured absolutely. This information can be used to derive the emissivity of the target, which is not directly determinable from passive data alone. Thus, active imaging can greatly enhance the value of passive data collections.

The ISTEF active imaging systems use pulsed illuminators. This has several advantages. First, target range is known. Second, pulsed systems have longer operational ranges than CW systems. Lastly, with our short pulses we have no motion blur in our images, even for the fastest targets.

As mentioned on the previous slide, the ability to discriminate objects very closely separated in range is another big advantage of range gated imagery. This capability is especially applicable CSO discrimination and cruise missile detection.

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Titan-Cassini Range Safety Concerns

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- RTGs (radioisotope thermoelectric generators)

  Because of the radioactive nature of the RTGs, ER Range Safety was concerned about the possibility of an *intact impact* of the Titan IV booster, since this generates the highest probability of radioactive contamination.

- SRMU (solid rocket motor upgrade)

  The updated SRMs have gimbaled nozzles -- this increases the possibility of an *intact impact* during the first seconds of launch.

- Cassini Night Launch:

  It was determined that the existing Eastern Range assets could not reliably image the Titan IV rockets during the first 20 seconds of a night launch because of the brightness of the SRMs. This also increased the risk of an *intact impact*.

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ISTEF was asked by the Air Force Eastern Range (ER) to help devise a system to insure the safe launch of the Titan-Cassini rocket. This request stemmed from three unique features of this launch. One, because of the presence of radioisotope thermoelectric generators (RTGs), ER Range Safety was concerned about the possibility of an *intact impact* of the Titan IV booster with the ground, since this scenario generated the highest probability of radioactive contamination. Second, this Titan was only the second launch scheduled to use the new solid rocket motor upgrade or SRMU. The updated solid rocket motors have gimbaled nozzles -- this increased the possibility of an *intact impact* during the first seconds of launch. Lastly, the launch was at night and it was determined that the existing Eastern Range assets could not reliably image the Titan IV rockets during the first 20 seconds of a night launch. This was because the extreme brightness of the SRMUs blinded the existing range cameras.

The main goal of ISTEF was to provide the ER with a means of *visually* determining the orientation and integrity of the Titan vehicle during the first 20 seconds of flight. The emphasis on visual is important since the ER Range Safety officers (the persons who can safely destroy the vehicle) feel that visual cues provide a less ambiguous and more natural means of verifying the vehicle status than other means, such as telemetry.

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The Solution

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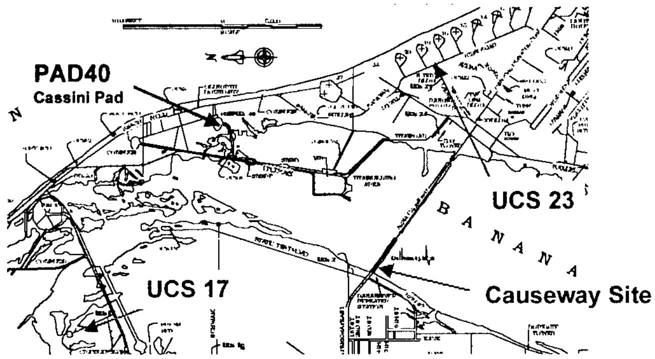
- We developed a Laser Imaging System (LIS) that was immune to plume effects during night launches
- We used 3 systems to provide redundant coverage for the Titan-Cassini launch
- The systems provided real-time laser images at video rate (30Hz) to the Range Safety officers console.

LIS testing using STS-85



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The solution that ISTEF proposed, and the ER accepted, was to build 3 laser imaging systems (LISs) and situate them at different azimuths around the launch pad. Each system used a doubled Nd:YAG laser illuminator and an ICCD Imager.

These LISs provided real-time video (laser) images to the ER range safety officer who used them to determine the stack integrity and orientation of the vehicle during the first 20 seconds of launch. Thus, the Laser Imaging Systems were a launch constraint; without them, Titan-Cassini would not launch.

The diagram above shows the location of the 3 LISs relative to launch complex 40. Two of the laser systems were operated by BMDO personnel and one was operated by Eastern Range personnel who were trained by ISTEF. One ISTEF operated system was located at Universal camera site 17 which was 7.5km from the launch site. The other ISTEF operated site was located on the west end of the NASA Causeway and was 6.4km from the launch site. Lastly, the ER operated site was located at universal camera site 23 which was 6.8km from the launch site.

The Cassini spacecraft was launched before dawn on the 15th of October from pad 40 at Cape Canaveral Air Station in Florida. All 3 imaging systems sent high contrast video, in real time to Range Safety where they were used to determine the stack integrity and orientation of the Titan launch vehicle.

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Unique Challenges

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- Laser Imaging: **Laser imaging is a new technology, which made the system high risk.**
- Laser Safety: **Laser System will produce an eye laser hazard**
- Short Development Time: **Approximately 18 months from concept to final application**
- Mission Critical: **The Cassini launch COULD NOT launch without the Laser Imaging System. During launch, the Range Safety Officer (person who can destroy the rocket) used the LIS system as a primary means of determining if the rocket flight was nominal.**
- Integration: **The system was integrated with the Air force Eastern Range range safety assets.**

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ISTEF's support of the Eastern Range during the Titan Cassini launch posed several unique challenges. These included: the use of laser imaging and associated laser safety issues, a very short development time, a mission critical application, and integration with other ER Range safety assets. Laser imaging is a new technology, which made the system more risky. To mitigate this risk we used, to the greatest extent possible, off-the-shelf parts. This had the double advantage of reducing risk while at the same time reducing cost. We also had to address the potential laser safety hazard associated with the pulsed laser source. This was solved by tightly coordinating our operations with those of the Eastern Range and Titan launch operations. The biggest challenge however, stemmed from the fact that the ISTEF systems were deemed mission critical and the Titan-Cassini vehicle *would not* launch without it. This meant that we had to take a mission critical system from concept to execution in 18 months.

The success of this program was due to a close working relationship between ISTEF and the Eastern Range. This close relationship greatly enhances our ability to support other BMDO and DOD programs at ISTEF. Also, the lessons learned in bringing a mission critical laser system from concept to execution in 18 months greatly enhanced ISTEF's expertise and capabilities. The result is that, ISTEF is now better able to support BMD programs such as DITP and ABL.

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Results

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Results

- ISTEF successfully supported the launch of the Titan-Cassini spacecraft using 3 laser imaging systems.
- All 3 systems sent high contrast video in real-time to Range Safety where they were used to determine the stack integrity and orientation of the Titan launch vehicle.
- The Laser Imaging System reduced the likelihood of an intact impact of the Titan vehicle and thus reduced the probability of radioactive contamination from the RTGs
- **Project Came in on-budget, on-time and performed flawlessly.**

BMDO Pay-off

- Gave ISTEF valuable technical knowledge about laser imaging which can be used to support BMDO programs such as DITP
- ISTEF used equipment from the Cassini project to support BMDO testing during operation DUNDEE. We will probably use this equipment to support upcoming testing for DITP
- Greatly enhanced BMDO and BMDO/ISTEF's reputation with the ER, making future operation much easer.

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ISTEF successfully supported the launch of the Titan-Cassini spacecraft using 3 laser imaging systems. All 3 systems sent high contrast video in real-time to Range Safety where they were used to determine the stack integrity and orientation of the Titan vehicle during launch. The ISTEF Laser Imaging Systems reduced the likelihood of an intact impact of the Titan vehicle and thus reduced the probability of radioactive contamination from the RTGs. Lastly, ISTEF demonstrated that it can support critical missions with new sensor technology and it can be done within budget and on time.

Supporting Titan Cassini gave ISTEF valuable technical knowledge about laser imaging which can be used to support BMD programs such as DITP and ABL. Also, equipment from the Cassini project was used to support BMDO testing during operation DUNDEE in Australia. Finally, the project greatly enhanced BMDO and BMDO/ISTEF's reputation with the ER, making future coordination faster and easier.

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Active Polarization Imaging

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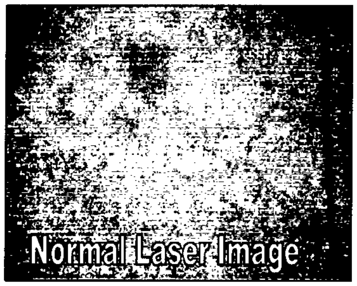
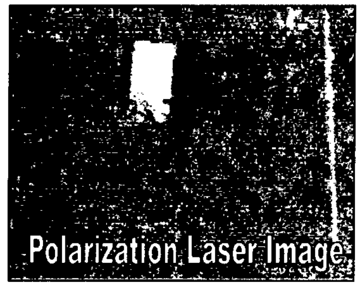
ISTEF, in cooperation with the University of Central Florida (UCF), is developing an active polarization imager. This system will be an ISTEF asset which will enhance ISTEF's active imaging capability.





<u>Benefits of Active Polarization Imaging:</u>

- Additional (new) signature information: degree of polarization/depolarization
- Man-made targets stand out against natural backgrounds
- Active polarization imaging works equally well day or night.

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Since most lasers transmit a well defined polarization, a natural enhancement to standard range-gated imagery is to include the ability to measure the target effect on polarization. The images above clearly show the advantage of a polarization sensitive system. The image on the left is a standard range gated image of a metal plate resting in a bush. The image at the right shows the same scene, but with the image intensity representing the degree of polarization of the reflected light. By using polarization sensing to augment standard range gated imagery, camouflage and concealment become more difficult. Also, since an active polarization imager provides its own target illumination, the presence or lack of ambient light does not affect image quality.

ISTEF, in cooperation with the University of Central Florida (UCF), is developing an active polarization imager. This system will become an ISTEF asset which will enhance our active imaging capability and will be used to support BMDO and DOD testing both at ISTEF and other test ranges.

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Polarization Imager

- Initial Goals
  - Build an active polarization imager at ISTEF
  - Imager will have a maximum range of 100km
  - Use visible laser as source
  - System will be *dual mode*: imaging and LADAR
- Current Status
  - ISTEF-CREOL team is currently in the design phase
  - Expect an operational prototype system in July/August '99
  - Final configuration by September/October '99
- BMDO Applications
  - Target identification
  - Target discrimination
- Future Goals
  - Make system portable
  - Make system "eye-safe"
  - Real-time processing

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The goal of the ISTEF-UCF polarization imager program is to build an active polarization imager that will become an ISTEF asset. This imager will have an operational range of 100km for uncooperative targets and use a visible pulse laser as it's source. Another important goal is to have the system work in a dual mode -- as an active polarization imager and a direct detection LADAR.

We are currently in the final design phases and are evaluating potential hardware. The system will use a pulsed, doubled Nd:YAG laser as the illuminator. All image information will be recorded digitally and will be post-processed to recover the polarization images. A prototype system is expected to be operational in August with the final configuration operational in September. Future upgrades to the system will make the system portable, eye-safe and capable of real-time processing of the polarization images.

Active polarization has all the advantages of standard range-gated imagery plus the ability to sense the polarization effects of different materials on laser light. This makes polarization imaging ideal for discrimination and identification of targets. On especially promising application would be low altitude cruise missile defense (CMD), where one must discriminate between a man-made object and a natural background.

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Summary

- The ISTEF Active Imaging program combines research into new detection methods with BMDO relevant field collections to enhance both BMDO's tests and ISTEF's research.
- ISTEF has demonstrated the capability to actively image surrogate BMD-threat targets. This data is of utility to all aspect of BMD from target discrimination to target identification.
- ISTEF is currently extending it's active imaging capabilities to include an active polarization imaging. This will enhance ISTEF's ability to support future BMD interceptor testing.

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The ISTEF active imaging program combines research into new imaging methods with BMDO relevant field collections to enhance both BMDO tests and ISTEF's research. We have demonstrated the capability to actively image surrogate BMD-threat targets. This data is useful in all aspects of BMD, from target discrimination to target identification.

ISTEF is currently extending it's active imaging capabilities to include active polarization imaging. This will enhance ISTEF's ability to support future BMD interceptor testing.

Our continuing research into active imaging methods and our ongoing support of BMDO and DOD programs go hand-in-hand. The synergy between application and research enhances our ability to support BMDO research and testing with active sensors.

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